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THE TOXIC EFFECT OF CERTAIN COMMON SALTS OF THE SOIL ON PLANTS

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(WITH ONE FIGURE)

A number of investigations have been made upon the action of single salts on plants, but in the majority of cases the object has been to determine the limit of endurance or the highest concentration at which the plants could live in the pure salt solutions. These concentrations vary with the salts used, and from the tabulated results it is not possible to tell the difference in growth of plants in the various salts in equimolecular solutions, nor would it be safe to assume this difference to vary uniformly at all concentrations. On a-priori grounds the reverse might be thought to be true, i. e., comparative degree of toxicity of certain solutions at one concentration might be entirely different at another. Again I have found time to be a very important factor in changing this relation, so that experiments lasting only a short period cannot be considered conclusive. The work done by previous investigators[1] differs so greatly in method, and the results are so scattered that no useful comparison with my results is possible.

Wheat was chosen as a well-known agricultural crop, and one with which much experimental work has been done. One variety only was used, the "Early Genesee," which contains a large proportion of starch, and which in preliminary experiments was found to germinate evenly and with a high percentage of germination. Radish and clover seeds were also used for comparison and found to give similar results to wheat.

In practically all experiments that have been made along this line, the seeds to be tested were first germinated in distilled water, then placed in the solutions. As the object of this investigation was to find the growth made by the seeds in the different solutions, this method was not practicable, and the seeds were supported on filter paper[2] so that they might germinate in the solution from the beginning.

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[1] References given at the close of the following papers include most of the literature on this subject: "Toxic limits and stimulating effects of some salts and poisons on wheat," by G. H. JENSEN in BOT. GAZETTE 43:42. 1907; also "The variability of wheat varieties in resistance to toxic salts," by L. L. HARTER, U. S. Dept. Agr., Bur. Pl. Industry, Bull. 79. 1905.

Twenty or more seeds were placed in each solution. In general the germination was quite uniform. Usually seven duplicate series of experiments were made. While some series made a better growth than others, the comparative order of toxicity was not changed. In all concentrations final examinations were made when the roots had reached the limit of growth. The solutions were all titrated against standard silver nitrate solution in the beginning and great care was taken in making up the various concentrations.

To keep the solutions at the same strength was a problem which received careful consideration. As little salt was taken by the plants the first few days, it was found perfectly safe to replenish the loss due to evaporation by adding distilled water. When the solutions were found by titration to be too weak, however, they were replaced by fresh solutions.

Several concentrations of chlorids of Ca, K, Na, and Mg were used, these salts being taken because they represent the bases most common in the soil. In order that the effects of the cathions might be clearly evident, only one anion, chlorion, was used. Control experiments with tap and distilled water were always carried on with each series, the water having been distilled with especial care to avoid all traces of metals in solution.

The plants made a better growth in distilled water than in any of the salt solutions, which were thus shown to exert a toxic rather than a stimulating effect at the concentrations used. While a marked difference in the degree of toxicity of Ca, Mg, K, and Na was clearly noticeable in the roots, the tops were more nearly alike in equimolecular solutions of the salts, except in the stronger concentrations of $MgCl_2$, in which little growth of either roots or tops occurred.

The order of germination was noteworthy. The seeds in KCl and NaCl were the first to send out roots, and for several days remained in advance of those in $CaCl_2$ and $MgCl_2$. For the first five days the wheat in the $MgCl_2$ solutions made a growth almost equal to those in $CaCl_2$, but after fifteen days the roots in the $MgCl_2$ were dead, while those in the $CaCl_2$ series were still living, even in such high concentrations as 0.12 *m*. After twenty or twenty-five days the plants in $CaCl_2$ solutions were in advance of those in KCl and NaCl. In all the solutions the limit of growth was reached in about thirty days.

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[2] The method is described by OSTERHOUT, BOT. GAZETTE 44:259. 1907.

It is significant to note the effect of these salts on the general appearance of the roots: $CaCl_2$ favored the development of root hairs; a fine growth of these occurred in the 0.06 *m* solution and throughout all the lower dilutions of the series. Also many side branches were produced, making a thrifty-looking root system.

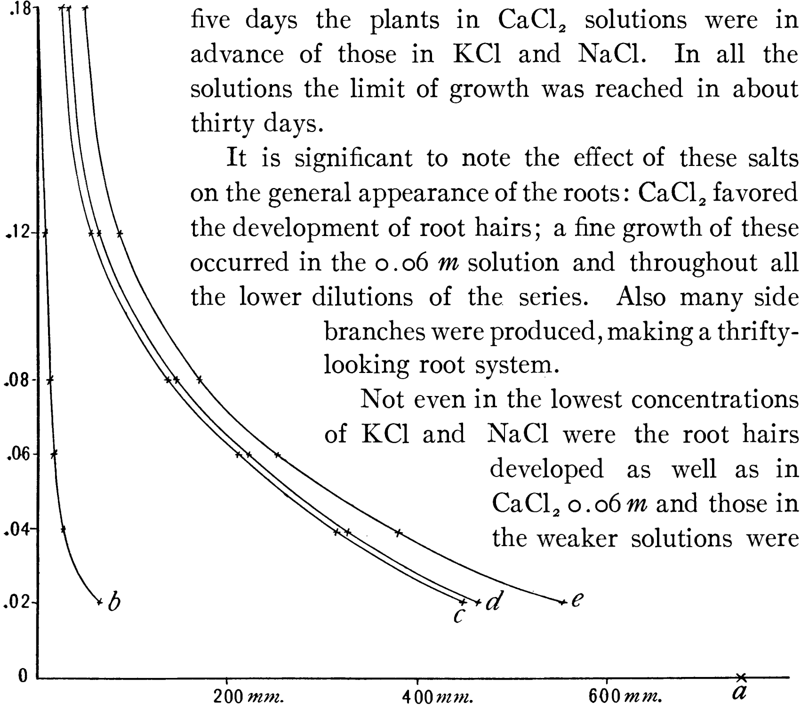

FIG. 1.—Curves showing the growth of roots of wheat in salt solutions; *a*, distilled water; *b*, $MgCl_2$; *c*, NaCl; *d*, KCl; *e*, $CaCl_2$. The ordinates represent concentrations (parts molecular); the abscissae, the aggregate length of roots per plant (in millimeters).

Not even in the lowest concentrations of KCl and NaCl were the root hairs developed as well as in $CaCl_2$ 0.06 *m* and those in the weaker solutions were decidedly unthrifty in appearance. In KCl the roots had a dull white color, and as to branching were next to $CaCl_2$, although the branches were thicker and shorter than in $CaCl_2$; the branches were most abundant at 0.02, 0.04, and 0.06 *m*. In $CaCl_2$ branching was practically the same throughout. In NaCl a few stunted branches developed and after twenty days the roots were of a yellow color in all the higher concentrations, down to 0.02 *m*. In $MgCl_2$ neither branches nor root hairs were produced in concentrations 0.08 *m* to

0.005 *m*, but in 0.001 *m* root hairs were developed, and in 0.0001 *m* branches were sent out similar to those in $CaCl_2$ solutions.

The following table gives the average length of roots per plant produced in the various solutions, the figures being based on seven duplicate series of experiments.

SALTS	CONCENTRATIONS					
	0.02 *m*	0.04 *m*	0.06 *m*	0.08 *m*	0.12 *m*	0.18 *m*
$MgCl_2$	64^{mm}	26^{mm}	15^{mm}	10^{mm}	6^{mm}	0^{mm}
NaCl	446	321	210	134	54	24
KCl	462	333	220	144	63	31
$CaCl_2$	552	386	249	168	84	48

Distilled water, 740^{mm}

These results are also shown in *fig. 1* in the form of curves, the concentrations being used as ordinates and the average length of the roots per plant being used as abscissae. The curves show that little growth took place at 0.18 *m* in sodium, potassium, and calcium chlorids, and none whatever in magnesium chlorid. The small growth in magnesium chlorid throughout the whole series of concentrations is due mostly to its toxic action; but also in some degree to its higher osmotic pressure. The molecule of $MgCl_2$ when dissolved dissociates into three ions instead of two, as in the case of NaCl and KCl; hence $MgCl_2$ solutions have a higher osmotic pressure than equimolecular solutions of NaCl and KCl.

All the more striking is the behavior of $CaCl_2$ which in spite of high osmotic pressure (approximately as high as $MgCl_2$) nevertheless permits greater growth than NaCl or KCl; hence it must be much less toxic than any of the other salts.

RESULTS

1. Each of the principal soil bases (Na, K, Mg, Ca) is toxic. The following is the order of toxicity of their chlorids: (1) $MgCl_2$, (2) NaCl, (3) KCl, and (4) $CaCl_2$.

2. Experiments lasting but a short time (such as have been made by most previous investigators of the toxic action of salts) cannot be considered as conclusive as longer experiments. After six days,

plants in NaCl and KCl made more growth than in $CaCl_2$, but after twenty-five or thirty days the plants in $CaCl_2$ were in advance of all the others.

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